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Division of

POLICY RESEARCH AND ANALYSIS

PROGRAM ANNOUNCEMENT AND SOLICITATION

ORIGINAL

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Scientific, Technological and International Affairs Directorate
National Science Foundation, Washington, D.C. 20550

DIVISION OF POLICY RESEARCH AND ANALYSIS PROGRAM ANNOUNCEMENT AND SOLICITATION

INTRODUCTION

This booklet is issued to stimulate the submission of unsolicited proposals for research on science and technology policy issues of national concern, and to solicit formal proposals in response to a set of specific research topics. Guidance for participation in these activities is presented below in the **PROGRAM ANNOUNCEMENT** section for *unsolicited* proposals and the **PROGRAM SOLICITATION** section for specific proposal requests. The Foundation welcomes proposals on behalf of all qualified scientists and engineers, and strongly encourages women and minorities to compete fully in any of the research and research-related Programs described in this document.

The Division of Policy Research and Analysis (PRA) conducts an extramural applied research program on Federal science and technology policy issues, and on methods for improving the process and techniques of policy analysis. Development of information, knowledge, and methods which are relevant to perennial or emerging issues, and immediately useful to practicing policy analysts is emphasized by PRA. Investigators and organizations interested in pursuing more fundamental research in the policy sciences, or exploring generic issues relevant to state and local governments and the private sector, are referred to the Division of Social and Economic Sciences in the Directorate for Biological, Behavioral and Social Sciences, or other Divisions in the Directorate for Scientific, Technological and International Affairs, as listed in the Catalog of Federal Domestic Assistance Number 47.053.

The Foundation is statutorily mandated to provide information to other Federal agencies on science and technology policy issues. This function is assigned to PRA. In addition, PRA is often asked to provide factual information to the Director of the Foundation and the National Science Board on critical science and technology policy issues. PRA's involvement in these activities benefits both the Government (by feeding new research results into Federal policy decisions much sooner than otherwise possible) and the policy analysis research program (by fostering more directed, relevant, and useful research projects).

PROGRAM ANNOUNCEMENT FOR UNSOLICITED PROPOSALS

The Division of Policy Research and Analysis encourages the submission of *unsolicited* proposals for research on science and technology policy issues of national concern. It is suggested that proposal scope be limited to one to three person-years of effort, and that periods of performance be a year or longer. Short duration projects are preferred, all other factors being equal, because of PRA's desire to incorporate new knowledge into the policy process as soon as possible. As with other NSF unsolicited proposals, cost sharing is required (see page 4).

PRA's program is divided into three functional sections, each having specific objectives and topics of current interest. Direction of proposals toward a specific section is not mandatory, but will assist the proposal review and evaluation process. The three Sections are described below, along with current general areas of interest.

Science and Innovation Policy Section

The Science and Innovation Policy Section analyzes the impacts of Federal and foreign government policies on U.S. science and industry (in the aggregate) and their contributions to national goals. (Issues related to specific scientific fields or technologies are the responsibility of the Technology and Resource Policy Section, and are discussed below.)

Generic research areas are policy-relevant aspects of (1) the determinants and impacts of basic scientific research, and (2) the determinants and impacts of industrial research and development (R&D) and technological innovation. For empirical examination of aspects of these areas, improved measurements and analytic approaches are often desirable. Examples of typical research topics include:

- the effects of government measures (e.g., patents, research grant provisions, funding) on the contributions of scientific research to technology and the economy;
- the effects of government programs to strengthen the

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scientific infrastructure (e.g., trained personnel, research equipment) on the efficiency and effectiveness of U.S. research and innovation;

- interactions among research funding sources (e.g., governmment vs. private), approaches to research (e.g., government laboratories vs. industry laboratories), and the quantity, quality, and character of scientific research results;
- the factors which influence the transmission of research results to the industrial sector and subsequent use of such results;
- the contribution of science, both university and industrial, to the Nation's economy;
- the effects of U.S. and foreign governments' policies to stimulate industrial R&D or otherwise to promote industrial development, either industry-specific or economy-wide, on industrial innovation and international economic competitiveness;
- the effects of regulations for technology (e.g., performance or health-related regulations, export controls) on U.S. and foreign industrial R&D and on international technology transactions;
- the factors affecting the degrees to which U.S. firms and foreign competitors exploit the existing, worldwide stock of technology; and
- the factors which affect the incentives to innovation.

Technology and Resource Policy Section

The Technology and Resource Policy Section analyzes the relationships among government policies and specific technologies, industries, and natural resources. Typical problems of recent concern include the effects of regulatory policy on technology, compliance costs, and environmental quality; stockpiling, materials substitution, and information-related aspects of resources policy; the effects of Federal policy on the development of new energy, materials, and enviromental technologies; and the effects of new information and communications technologies on government organization and productivity.

Examples of specific problems and questions which would be appropriate for unsolicited proposals include the following:

- cost-effectiveness of current environmental monitoring programs, and the relationship between monitoring technologies and environmental policies;
- impacts of new biotechnology products on the environment, employment, industry, and mineral resources demands;
- Federal policy options utilizing new communications, computer, and information technologies to enhance selection and dissemination of Government-generated data;
- implications of new communications and information technologies on workforce training and education, and appropriate Federal responses;
- implications for Federal Government communications needs and uses arising from the new, competitive communications environment; and
- ways for the Federal Government to transfer the products of R&D programs in specific technology areas such as space and energy to the private sector.

Policy Sciences Section

The Policy Sciences Section reviews, evaluates, and develops assessment and analysis techniques to improve public policy analysis and decisions on Federal scientific and technological issues. Typical research questions addressed in the Policy Sciences program include the use of policy analysis in policy decisionmaking, treatment of uncertainties about the future in the analysis of both near-term and long-term policy options, the relation between analytical methods and other approaches to resolving policy problems, and contributions of policy analysis to the pattern of policy design and political action. Examples of typical long-term Policy Sciences issues follow:

- the development and evaluation of techniques for identifying and creating potential solutions to S&T public policy problems, such as risk management;
- the development and evaluation of improved methods for making use of scientific, technical, and other data bases in policy analysis and policymaking;
- the development and evaluation of methods for making use of sparse data sets in policy analysis;
- the development and evaluation of improved methods for making use of scientific expertise in policymaking;
- the development and evaluation of improved value-of-information analysis techniques;
- the proper role of policy analysis, as compared to other means (e.g., public participation) in the public policymaking process;
- the relationships among policy design, implementation, and evaluation;
- the advantages and disadvantages of alternatives to regulation for managing technological risks; and
- the development and evaluation of policy science curricula that more effectively link policy science research results with the practice of policy analysis.

Letters of Interest

Before preparation of formal unsolicited proposals in response to this announcement, proposers are encouraged to submit a letter of interest which summarizes in two or three pages the following points: policy issues of concern; research questions to be addressed; research approach; intended study participants; and rough estimates of the cost and duration of the project. Letters of interest should be addressed to the appropriate Section or to the Division of Policy Research and Analysis, 1800 G Street, N.W., Washington, D.C. 20550.

Authors of these letters will be advised of the likelihood that the proposed work would be judged consistent with program objectives, priorities, and standards, and likely to have utility for policy analysts at the time the project would be completed.

Formal proposals should be submitted in accordance with specifications provided in this document. Formal proposals are subjected to peer review conducted by professionals external to the Foundation, who are knowledgeable in the proposal topic, and selected to represent a balance of interests. Reviews are based on the standard criteria shown on the Evaluation Sheet in Appendix B.

Unsolicited letters of interest and proposals may be submitted at any time. However, formal proposals submitted before March 15 have the greatest likelihood of having a funding decision made during that fiscal year (which ends September 30).

PROGRAM SOLICITATION

In addition to the general areas of interest discussed in the preceding program announcement, there are several specific topics which are of immediate priority for additional research and information. Each of these topics is presented in Appendix A by program section. **PRA HEREBY SOLICITS DETAILED FORMAL PROPOSALS FOR RESEARCH PROJECTS TARGETED AT THESE SOLICITATION TOPICS.** Formal proposals should emphasize the performance aspects of the research design, including data and information sources, analytical methods, project plan, and the character of expected results. Cost sharing is not required. Letters of interest should not be submitted in response to the solicitation of this section; interested parties should submit final proposals directly.

PRA anticipates allocation of approximately $1.5 million for these solicitation topic awards this year. The level of effort for each award should be comparable to that described for unsolicited proposals, i.e., one to three person-years of effort. Awards will be made to the best one or two proposals for each solicitation topic, as evaluated by peer review. Peer review will be based on the same review form used for unsolicited proposals, with the exception that criterion 1, "Relevance of Proposed Research for S&T Public Policy Issues," will be omitted. If peer review determines that none of the proposals submitted are responsive, PRA reserves the right to decline funding on that particular solicitation topic. **ALL PROPOSALS FOR FISCAL YEAR 1984 SOLICITATION TOPICS MUST BE RECEIVED BY THE FOUNDATION ON OR BEFORE APRIL 15, 1984.**

Projects may be designed for multiyear funding, but PRA reserves the right to reevaluate the merit for future funding based on annual project progress reviews. All other factors being equal, projects designed to deliver substantive, useful annual progress reports will be favored.

PROPOSAL DEVELOPMENT AND SUBMISSION

Formal Proposal

Twenty (20) copies of each formal proposal, both unsolicited and solicited, bearing all required official signatures, should be sent directly to:

Central Processing Section
National Science Foundation
1800 G Street,N.W.
Washington, D.C. 20550
Attn: Division of Policy Research and Analysis

A separate information copy should be sent directly to PRA.

Target Dates

Unsolicited formal proposals may be submitted at any time during the year, but those submitted prior to March 15 will have the greatest likelihood of being funded during that fiscal year. Solicited proposals must be submitted prior to April 15, 1984. Approximately six months should be allowed for review and decision following the receipt by NSF of a formal proposal.

Proposal Format and Content

Proposals should cover the items listed below in general accordance with the guidelines contained in the NSF Brochure, *Grants for Scientific and Engineering Research* (NSF 83-57). Proposals should be direct, concise, and informative. All items should be covered in the order shown.

1. Cover Sheet—see Appendix B for format.
2. Abstract—not more than one page. Include identification of the problem and a summary of the approach, project objectives, anticipated results, and implications of the project results.
3. Identification and Significance of the Issue(s)—a discussion of the specific issue being addressed and its importance. A discussion of the significance of the contribution the project will make to science and technology policy information should be included.
4. Project Plan—a discussion of the specific hypotheses or research questions, the conceptual framework or model to be used, the literature and/or data to be used in the project, the data collection and analysis plans, and continuing efforts. Plans should also include procedures to be used to insure objectivity and balance in the project. Plans for evaluation

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should also be discussed in this section. This section should receive special attention in Program Solicitation Proposals.

5. Related Efforts—a description of significant related studies conducted by members of the project staff or by others, and discussion of any planned coordination with other work in the field.

6. Final Report and Dissemination—the plans for dissemination of project outputs to relevant audiences should be discussed. The proposal should agree to provide a master/original final project report plus 50 copies, and 100 copies of an executive summary to PRA not more than ninety days following the end of the award period. The proposal should acknowledge that the final report will be evaluated according to regular PRA guidelines.

7. Project Personnel and Bibliography of Directly Related Work—brief curricula vitae for the professional staff, summarizing education, related experience, and bibliographic information related to the proposed work.

8. Institutional Qualifications—should cover the resources available at, and the relevant experience of, the institution. Resources include personnel, computer, and library facilities, and ties to both sources of data and potential users of the results.

9. Project Management Plan—should include the time and cost schedule for the proposed work and the time allocations and responsibilities for the project staff members. It should also schedule progress reports.

10. Current Support and Pending Applications—a listing of all sources of support, in addition to the proposed effort, to which the senior research personnel have committed a portion of their time for the period of time covered by the proposal. The information should account for 100 percent of the work time of the senior investigators, and include titles, dates, and grant numbers of current grants or contracts, source of funds, annual budget levels, and the person-months committed in each case. The proposal must also list research which is being considered by or will be submitted to other possible sponsors, including other NSF programs. Concurrent submission will not jeopardize the likelihood of an award.

11. Budget—a proposal budget should be prepared in the format presented in Appendix B. Where the total cost of the proposed effort is expected to exceed the budget requested from NSF, proposers must indicate the sources from which additional funds are committed and the amounts of those funds. Unusual items should be fully explained or justified as budget notes.

    Proposed costs should be known costs if possible; estimates should be given only when it is impossible to ascertain actual costs. Nonspecific items grouped as "miscellaneous" or "contingency funds" should not be included. The budget should not include items for expenses incurred before the date of the award, such as staff time required to prepare the proposal or to make initial preparations for a conference.

    Budgets should specifically list, as separately numbered items, any permanent equipment that will cost $1,000 or more. Estimated airfares should not normally exceed round-trip jet economy class. Subcontracts should be listed under "All Other Direct Costs" and described on a separate budget form. The subcontract budget should be approved and signed by the proposed subcontractor, which should indicate the latter's agreement to perform the work described in the proposal.

    The proposing institution is entitled to indirect costs at the rate approved for that institution, which can be obtained from its business office, or from the NSF Division of Grants and Contracts, Cost Analysis Section. Budgets for unsolicited research proposals should contain a statement that the institution will share costs in accordance with NSF policies. For further information on cost-sharing, see NSF Grant Policy Manual [GPM (NSF 77-47, revised)], Section 640, and Important Notice No. 81, February 1980.

Privileged Information

Since the proposal is considered an integral part of the award instrument, proposals resulting in awards may be made available to the public. However, trade secrets and business information such as salaries of key personnel will be treated in confidence if this information is prepared in a separate statement rather than in the text of the proposal or in the budget itself. Two copies of these separate sheets or salary schedules should be attached to the original proposal only and should contain a legend similar to the following: "It is requested that the following (specify business information, salary schedule or trade secret) not be released to persons outside the Government." These separate sheets must be signed by the official who endorses the proposal. Without assuming any liability for inadvertent disclosure, NSF will seek to limit dissemination of such information to its employees and, where necessary for evaluation of the proposal, to outside reviewers. In any case, NSF will not be limited in using similar information obtained without restriction from another source.

A proposal that does not result in an award may be retained by the Foundation. Such a proposal will be released only (1) with the consent of the proposer, or (2) to the extent required by law. A proposal may be withdrawn at any time prior to final action by the Foundation.

First-Time Applicants

In the event that the submitting organization has not recently been the recipient of an NSF award, it is recommended that appropriate administrative officials be familiar with the NSF policies and procedures contained in the NSF *Grant Policy Manual* (NSF 77-47, revised), which are applicable to most NSF awards. Copies of the Manual may be ordered directly from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

If the submitting organization has not already done so, it should be prepared to furnish the following to the NSF Division of Grants and Contracts on request:

> Basic information regarding organization and management, as outlined in Section GPM 340, Prospective Grantee Organization and Management Data, of the Manual, with particular reference to the most recent certified financial management statement required of nonacademic organizations.
>
> An assurance of compliance with the NSF regulation under Title VI of the Civil Rights Act of 1964, as outlined in Section GPM 700 of the Manual.
>
> Identification of the cognizant Federal negotiating agency which has approved the organization's indirect cost base and rate(s) and the date of the most recent negotiation. If the submitting organization does not have a federally approved indirect cost base and rate(s), the business officer should be prepared to submit an indirect cost proposal, as outlined in Section GPM 201d of the Manual, when requested to do so. Contents and financial data included in indirect cost proposals vary according to the nature of the proposing organization. Appropriate guidelines may be obtained by writing the Cost Analysis Section, Division of Grants and Contracts, National Science Foundation, 1800 G Street, N.W., Room 206, Washington, D.C. 20550.

Awards to Individuals

NSF does not normally make awards to individuals acting independently of or not affiliated with an institution or organization. For further information, see Section 203.1 of the GPM.

Award Information

The Foundation provides awards for research in the sciences and engineering. The awardee is wholly responsible for the conduct of such research and preparation of the results for publication. The Foundation, therefore, does not assume responsibility for such findings or their interpretation.

There is no NSF commitment to make any specific number of awards. Most awards under this announcement or solicitation are expected to be grants. Proposals submitted in response to the program announcement are considered unsolicited. Each award will contain appropriate general and specific provisions according to standard NSF and government practice. Awards may also contain other special provisions as necessary. These may replace or modify certain general provisions. Specific information on NSF policies concerning intangible property such as copyrights and patents appears in Sections 750-760 of the GPM.

PROJECT MONITORING AND ADMINISTRATION

The Division of Grants and Contracts of NSF monitors management practices and fiscal matters concerning awards. Substantive and technical monitoring will be conducted by the PRA staff. It is expected that many of the institutional delegations generally made under the Organizational Prior Approval System will not be provided under awards made by PRA. Procedures and policies for administration of NSF grants are contained within the NSF Grant Policy Manual (NSF 77-47, revised).

DEADLINES AND TARGET DATES

The earliest starting date for 1984 awards will be July 1, 1984; the latest is June 30, 1985. Applicants wishing to start projects later than June 30, 1985, must wait for the 1985 competition. Applicants requesting a starting date prior to September 1 should have an alternate later date in the event that proposal processing cannot be completed by the proposed starting time. No funds may be spent prior to the effective date of the award; thus, applicants should set the starting date early enough to cover whatever period of time may be necessary for start-up expenses.

APPENDIX A
Solicitation Topics

Solicitation Topic No. 1

MEASURES OF SCIENCE OUTPUT

Prepared by:
Science and Innovation Policy Section
Division of Policy Research and Analysis

Problem

In its support of basic research, the Federal Government pursues a variety of goals: to solve specific problems, to expand fundamental knowledge, and to train scientific and technical personnel, among others. Federal officials strive to maximize the extent to which these goals are achieved relative to the resources devoted to them. It is easier to know whether some of these objectives have been met than others; the most difficult case is the expansion of fundamental knowledge. The aim of research supported under this topic is to explore ways of operationalizing concepts of knowledge growth which can be used in the retrospective evaluation and the anticipation of the knowledge "outputs" of scientific research activities.

Current Situation

Many questions which use such concepts arise in the science policy process, including the following: What are the relative scientific dividends across research areas which are likely to result from incremental funding at a particular point in time? What are the probable knowledge-generating effects of proposed special programs for instrumentation, post-doctoral support, etc.? How can the research performance of major scientific facilities be assessed? What has been the impact of a funding agency on the development of a particular scientific field?

The main source of information currently used in response to these questions is the judgment of the scientific community about its own past accomplishments and prospects for future ones. In evaluating the performance of research units, the judgments of scientists are sometimes supplemented with data which are thought to express the collective assessment of the relevant scientific communities; such data include peer evaluations gathered through survey instruments and publication and citation counts. (The use of such data is discussed in a number of sources, including Narin et al., 1976; Moed et al., 1983; and Martin and Irvine, 1983). Even for evaluative purposes, the usefulness of these techniques is limited. They do not differentiate among the many complementary roles which research units can play within a scientific field and they do not provide valid interfield comparisons.

In answering more complex policy questions, the application of publication and citation counts is even more limited, because the growth of knowledge in a scientific field cannot be equated with the summed "performance" of its research units. Some policy research has attempted to overcome these limitations by focusing on "important events" in science. For example, the role of funding agencies in advancing particular scientific fields has been studied by asking active scientists to identify the major advances within them, then tracing the sources of support for the work identified (Kruytbosch, 1978). Another study draws policy conclusions from the analysis of conditions associated with discoveries (Harwit, 1981).

From the viewpoint of current theories of scientific development, empirical methods which equate scientific knowledge growth with either "performance" or "discovery" are misleadingly simple. Prevailing theoretical orientations (for example, Kuhn, 1962; Merton, 1973; Knorr, 1981) treat discoveries as the product of a range of conditions, individual, cultural and social, within and beyond the scientific fields where the discoveries occur. In this view, the funding agencies which supported the particular scientists who "made" a discovery may have had no more impact on that achievement than the agency which supported their competitors or the one which developed the instrument used; all their support is interdependent. Furthermore, while in one field experimental breakthroughs may generally depend on improvements in instruments, in another field they may rest on theoretical advances; and these forms of interdependence can change within a field over time.

Theory points to the limitations of the simplest "output indicators" but has stimulated only a few alternatives (e.g., Small, 1977; and Callon et al., 1983). To produce systematic information on the impact of past funding decisions, science policy research requires descriptions of the development of knowledge in specific fields of science which reflect both the variety of contributions to science and their complex interdependence.

Research Agenda

This solicitation calls for proposals to develop more differentiated and inclusive quantitative descriptors of knowledge growth which can be adapted for use in a wide range of sciences. Proposals submitted under the solicitation should address the following questions:

What concepts are in use among scientists in a variety of fields to describe the contributions essential to the advance of knowledge in their research areas? Are some concepts common to all the sciences? Are these held to be equally important in all fields?

From the range of techniques currently available, what is the best way of operationalizing the concepts most frequently used among scientists to characterize scientific advance? Can the concepts be effectively operationalized in the same way in all the sciences? Is there a useful and empirically-based typology of differences among the sciences which describes the way they characterize advance in their stocks of knowledge?

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Solicitation Topic No. 2

TAX POLICY, R&D, AND INNOVATION

Prepared by:
Science and Innovation Policy Section
Division of Policy Research and Analysis

Problem

Recent concerns about U.S. economic development, productivity growth, and international competitiveness have led to claims that major U.S. trading partners offer significantly better tax treatment for research and development (R&D) and other innovative activities and that tax provisions have a significant impact on innovation. It has also been asserted that the new accelerated cost recovery system for investment, as introduced in 1981 and modified in 1982, has provided greater tax benefits to investment in smokestack industries than to investment in high technology industries. But claims about differences in tax treatment and impacts of differences on innovative activities have exceeded research evidence about the claims.

Current Situation

Specific problem examples are: (a) Do major U.S. trading partners offer significantly better tax treatment for R&D and other innovative activities? (b) What are direct effects of the R&D tax credit on investment in industrial R&D? (c) Does the new accelerated cost recovery system (ACRS) provide better tax treatment for smokestack than for high technology industries? (d) What are indirect effects of corporate tax provisions, e.g. the new ACRS, on R&D and other innovative activities? A summary of initial findings and gaps in evidence about these questions follows.

Documentation in early 1981 of the corporation income tax treatment of innovation in the United States and five major trading partners indicates that no one country provides uniformly more favorable tax treatment for innovation. This study did not, however, provide some overall measure or measures of each country's tax treatment that nets out the various "pluses" and "minuses" represented by the many provisions in each country's tax code (Division of Policy Research and Analysis (PRA) Research Report 81-1).

Initial assessments of an R&D tax credit found that such an incentive can have a direct positive effect on R&D, but the size of the effect depends on the presence of conditioning factors such as a company's overall market strategy and the general economic environment. This work provided analytical rather than quantitative assessments (Kaplan, 1976; PRA Research Report 82-1). Two studies have been recently initiated to provide comprehensive quantitative assessments of the direct effects of the R&D tax credit on industrial R&D (including foreign experience with an R&D credit) and on tax revenue. These studies have not reached final conclusions; progress to date is reported in Eisner, Albert, and Sullivan, 1983, and in Mansfield, 1983b.

Initial estimates of average and marginal effective tax rates for high technology and smokestack industries are reported in Fullerton and Lyon, 1983, and in Hulten and Robertson, 1983. Hulten and Robertson find that in the 1970's the high technology group experienced higher average but lower marginal effective tax rates than did the smokestack group. Both studies find that effective tax rates will be lower for both industry groups under current ACRS treatment, with the marginal effective tax rates for the high technology and smokestack groups being roughly equal. This work does not, however, measure the degree to which individual firms or subsectors might experience substantially higher effective tax rates in the high technology or smokestack groups. Nor does it assess the degree of responsiveness of industry decisions in high technology and smokestack sectors to differences in effective tax rates.

Evidence about indirect effects of corporate tax provisions, e.g. ACRS, on R&D and other innovative activities is sparse and is drawn primarily by implication from three interrelated bodies of work: analyses of the determinants of investment in plant and equipment (see, for example, Chirinko, 1983; and Visscher, 1976); analyses of the determinants of investment in R&D and other innovative activities (e.g., Kamien and Schwartz, 1975; Mansfield, 1983a; Nelson, 1981; and PRA Research Reports 82-1 and 83-1); and analyses of links between investment in capital goods and induced demand for investment in R&D in the capital-goods sectors (in particular, Scherer, 1981; and Schmookler, 1966).

Taken together these studies indicate that investment in plant and equipment, in R&D, and in other innovative activities are jointly determined by a set of interrelated factors. These include the relative cost of investment in plant and equipment, R&D, and later stages of the innovation process; the expected net rate of return on different investments; the cost of finance; cashflow or the level of sales; the firm's market expectations and overall market strategy; and the general business climate.

An implication of this work is that the tax code can influence innovation directly; for example, through the impact of the ACRS treatment of R&D equipment on the "net-of-tax" cost of R&D equipment purchases; and the tax code can influence innovation indirectly, for example,

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through the impact of ACRS on the level and composition of investment in plant and equipment. In particular, a general reduction in average effective tax rates can increase cashflow from which additional investment can be financed; a general reduction in marginal effective tax rates can encourage increased investment by increasing its net rate of return. Increased investment in turn helps to diffuse new technology and provides an incentive for increased R&D and innovation in the capital-goods sectors. In addition, the tax code can produce differential stimuli to different kinds of investment, causing shifts in the composition of investment in plant and equipment and thus in the composition of indirect incentives for R&D and innovation.

Assessment of indirect tax effects on innovative activities has been hindered by difficulties in obtaining sufficiently detailed data (e.g., about the spread in individual effective tax rates within high technology and smokestack sectors), controversies about the relative importance of different routes by which tax variables can influence investment and innovation decisions (e.g., via impacts on cashflow or on net rates of return), and disagreements over how these routes are conditioned by the larger market and institutional setting within which a firm operates. (For further discussion, see Chirinko, 1983; Eisner, 1983; and Kamien and Schwartz, 1975.)

Research Agenda

This solicitation topic is focused on developing better micro-level information and improved understanding of the series of indirect linkages between tax variables and innovation in order to develop a first-cut assessment of whether and to what degree the current tax treatment of business income exerts significant indirect effects on R&D or other innovative activities. The following sorts of questions are of interest: (1) What is the spread in individual effective tax rates around the group rate in the high technology and smokestack groups? For example, are there particular industry subsectors (e.g., electronics, autos) which experience substantially higher effective tax rates on investment (because, for example, they have insufficient net income to use the benefits of ACRS; the rate of obsolescence on their equipment is so rapid that the pre-ACRS "facts and circumstances" option for depreciation is preferable to ACRS; or their cost or method of finance is significantly different)? (2) If there are substantial differences in effective tax rates for particular subgroups, what is the likely impact (if any) on the level and composition of investment and innovation expenditures? For example, what is the responsiveness of investment in plant and equipment to changes in effective tax rates in these subgroups; and what is the responsiveness of R&D in major capital-goods sectors to tax-induced changes in capital-goods investment?

In view of the developmental stage of research methods that might be employed to address the questions above, proposers are requested to clearly state: (a) what research approach(es) will be employed in the analysis, (b) the appropriateness of the approach(es) for addressing the questions to be studied, and (c) any caveats that apply to the planned research.

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Solicitation Topic No. 3

FEDERAL STANDARDS SETTING

Prepared by:
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Division of Policy Research and Analysis

Problem

Governments have been involved in the setting of standards since the beginning of recorded history. Standards provide a basis for commerce, help to ensure health and safety, and promote economic efficiencies. Yet, standards can have disturbingly disbeneficial effects. Enacted too soon in the development of a new technology, or improperly, they can stifle technological development, impede innovation, and be a detriment to health and safety. The need for standards depends on many factors, not the least of which is the rate of technological development. Emerging technologies in areas such as computers and communications beg various forms of standardization. But the guidelines that the Government can follow in the establishment of standards in these areas are weak. The purpose of this research is to explore the possibility of establishing better guidelines for the Federal standards-setting process.

Current Situation

The Federal Government is involved in the process of setting standards in many ways: (1) as a large procurer of equipment, the Government may, de facto, set standards through the procurement process, (2) it is the job of an entire agency of the Government, the National Bureau of Standards, to set standards, and (3) many of the regulatory and operational agencies set standards as a matter of course in the discharge of their responsibilities. Standards may take one of four forms, depending on their function:

(1) *Information standards* provide terminology plus test and measurement methods for evaluating and quantifying product attributes,

(2) *Compatibility standards* specify properties that a product should have in order to be compatible with a complementary product or "system,"

(3) *Variety reduction standards* limit the product to having only a certain range of allowable characteristics such as physical dimensions, and

(4) *Quality standards* are developed to ensure an acceptable level of product performance along several dimensions including reliability, durability, efficiency, safety, and environmental impact.

These functions explain why and how a standard affects other elements in the overall decisionmaking framework.

Standards do, indeed, influence research, development, and innovation. Both products and processes are affected. Standards do this, in part, through their influence on corporate strategy. Standards may be used, in the case of a Federal procurement on a major system, to force research and development, and they may be used to prevent research and development, typically by locking existing suppliers into the marketplace.

Standards affect the choice and timing of innovation investment projects. These projects are generally selected on the basis of their expected value or rate of return. This value is, in turn, a function of the perceived risk associated with a project. Standards can alter the perceived risk by changing the probability of commercial success and by decreasing the technical risk. Sometimes new test and measurement methods must be developed before standards can be effectively set and enforced, and before products can be effectively marketed. Standards transmit information to the market.

The theory of standards-setting is not well developed. Much of the existing linkage between the standards-setting process, the form that the standards take, and their effect, economic or otherwise, is anecdotal. General and accepted mathematical relationships between, for example, a standard and the societal benefit that results are sparse. Consequently, the existing theory lacks a predictive capability necessary for policy analysis regarding any specific standard or its alternatives.

On the other hand, considerable anecdotal information on the standards-setting process does exist. Studies have been performed under the sponsorship of the National Bureau of Standards, and at a number of academic institutions, such as the Center for Policy Alternatives at the Massachusetts Institute of Technology. The Department of Economics at the University of North Carolina has studied voluntary product standards. The following propositions and hypotheses have been posited:

(1) The more complex the production process, the more difficult it is for buyers and sellers to agree on the performance attributes of products; therefore, the greater the demand for standards by both parties, ceteris paribus.

(2) The management of firms where the collective bargaining strength of unions is strong may favor production-related standards as a form of labor-saving technology.

(3) The degree to which an industry's products are standardized influences the firm's make versus buy decision.

The last of these has been represented mathematically, and some hope may be held out for modeling of other hypotheses.

Research Agenda

This solicitation calls for proposals to address a substantial subset of the following questions relevant to the standards-setting process:

- What are typical technologies for which standards have been established in the past;
- When in the development of each technology were the relevant standards established, and how was each such standard stated;
- In retrospect, what was the effect of each such standard: did it accelerate technological innovation or stifle R&D and/or innovation; did it broaden or reduce markets for the technology; and what effect did the standard have on the benefit that the technology provided to society;
- What has been the historical relationship between technologies and Federal standard-setting agencies, and what have been the historical forces arguing for and against the setting of standards;
- What are the lessons that can be learned from the above historical examination; and
- What normative rules should the Government apply to the standards-setting process in the future: when, in the lifetime of a technology, should the Government consider the establishment of standards, what form should such standards take; and how can the Government determine when it has established an improper, ineffective, or premature standard?

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Solicitation Topic No. 4

SCIENTIFIC AND TECHNOLOGICAL INFORMATION IN FEDERAL DECISIONMAKING

Prepared by:
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Problem

More and more of the issues facing high level officials in both the Executive and Legislative Branches of the Federal Government have important scientific and technological components. Relatively few of these officials have strong backgrounds in science and technology (S&T). In making decisions on such issues, these officials must, in general, depend on S&T information and advice provided by lower level officials, formal or informal S&T advisory groups, and others in the S&T community. Too frequently, however, decisionmakers find that the S&T information and advice they receive is conflicting, equivocal, irrelevant, or otherwise not very useful. Those who provide the advice, meanwhile, often feel it is neglected or misused by decisionmakers. The purpose of this solicitation topic is to explore the ways in which S&T information is used by Federal decisionmakers and to develop methods for improving the utility of such information to these decisionmakers.

Background

Users of S&T Information

Federal agencies and decisionmakers within these agencies use S&T information and advice for a variety of purposes. In regulatory agencies, for example, such information is needed to:

- uncover the existence of problems for which regulation is needed,
- assess risks,
- ascertain the costs and benefits of a course of action, and
- determine alternative means of alleviating a problem.

In other agencies and programs, S&T information and advice may be needed by decisionmakers in order to determine the need for, establish, and manage R&D efforts. These R&D efforts may be aimed at generating new knowledge or technology for the agency to use in pursuing its mission, serving broader public needs, or assisting private sector technology development activities.

In still other circumstances, decisionmakers may require S&T information and advice in order to make proper choices and carry out responsibly program mandates which involve scientific methods or technologies (although not R&D). Examples of such mandates include: weather forecasting, assisting localities in the construction of mass transit systems, or operating an air traffic control system.

Finally, Congress and agencies in the Executive Office of the President may need S&T information and advice in exercising their planning, budgeting, or oversight responsibilities in any or all of the above areas.

Expertise and Utility of S&T Information

In order for S&T information and advice to be useful to a decisionmaker, it must be accurate, complete, unbiased, up-to-date, and available in a timely manner. It must also be presented clearly, in a form comprehensible to the decisionmaker. Finally, it must be able to withstand the scrutiny of those, inside and outside of the organization, who disagree with the decision based upon it and who may well be capable independently of marshalling facts and arguments in opposition.

In many cases, the individuals making decisions or policy have little or no technical background. At best, these individuals may have some background in the technologies with which they are dealing, but seldom will they be experts in these areas. Furthermore, as a rule, the more important a decision is, the higher the organizational level it will reach. The higher the organizational level of the decisionmaker, the wider the range of decisions he or she must be involved in, the less likely he or she is to be expert in a given area, and the more dependent he or she is on good information and advice.

Obtaining reliable S&T information and advice is not a simple matter for a decisionmaker. While laypersons often view science as a straightforward means of finding "truth," the type of S&T information relevant to policy and decisionmaking is, in fact, often filled with ambiguities. As an observer has noted:

> The theories, models, procedures, and formulas of science and technology are generally believed to allow one trained in their use simply to calculate an unambiguously correct answer. A technologist or scientist soon comes to recognize that the complex technical problems of the state-of-the-art require subtle perceptions of the sort which cannot easily be articulated in explicit form. When it is necessary to make a simplifying assumption, and many are reasonable, which sim-

> plifying assumption should be made? When data are lacking on a question, how far may one reasonably extrapolate from data of other sources? How trustworthy is a set of empirical observations? These questions all require judgements for which there are no formalized guides. . . (Mazur, 1981: 20)

Facts and judgements are thus inescapably mixed in the S&T information that reaches a decisionmaker.

Time pressures compound these problems. Often, decisions cannot wait for the normal accumulation and validation of scientific knowledge. Decisionmaking is hurried by the urgency of problems or by demands for action by parties with a stake in the decision. There is no time to conduct additional studies or collect more data.

Finally, for S&T information to be useful to decisionmakers who are not themselves technically expert, it must be presented in a comprehensible manner, free of jargon and complex mathematical expressions, with conclusions clearly and unequivocally stated, but with areas of uncertainty delineated. The distillation of S&T information into this form is itself an art and requires considerable skill if it is to be done responsibly and in a manner which will satisfy both the S&T community and the relevant agency and decisionmaker. The higher the level of the decisionmaker, furthermore, the greater the amount of distillation required, the larger the element of judgement.

Research Agenda

These problems are not new. They are well known and have been the subject of considerable discussion, debate, and research. A few representative selections from the literature are listed in the bibliography below. The continuing dissatisfaction of policy and decisionmakers, as well as members of the S&T community with the processes by which S&T information and advice are used in Federal decisionmaking and (in many cases) with the results, suggests that additional work is needed. This solicitation requests proposals for research which will build on the base of existing studies, or, if necessary, take off in new directions in order to assist PRA in its mission of providing S&T information to policy and decisionmakers throughout the agencies of the Federal Government.

This solicitation calls for proposals to address a substantial subset of the following questions:

- Who are the principal Federal decisionmakers and policy makers who make use of nonmilitary S&T information and advice;
- For each user, what are their major sources of S&T information and advice, and what is their order of preference;
- For each user, what are their areas of expertise and how well equipped are they to deal with S&T information and advice;
- How does each user make use of such information;
- What criteria, in the users' opinion, characterize useful S&T information and advice;
- What examples of such useful information can be found and what counter-examples may be found with which it can be contrasted;
- Can case studies be found demonstrating how "good" and "bad" S&T information and advice was obtained and used by Federal decisionmakers;
- What methods exist for handling uncertainty in the generation and presentation of S&T information and advice to decisionmakers, and how well do decisionmakers make use of information when it is provided in this way;
- How is S&T information and advice obtained and used in other decisionmaking systems, e.g., the legal system or private industry;
- What lessons can be learned from this experience with the use of S&T information and advice that are relevant to the situation of PRA; and
- What guidelines should PRA apply to the content and form of the policy information it provides to its clients in order to maximize the value of this information?

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Solicitation Topic No. 5

ALTERNATIVES TO REGULATION

Prepared by:
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Problem

Federal concern with risk management has increased dramatically in recent years, as measured by the number of new health, safety, and environmental laws. Most of these laws have established regulatory mechanisms for risk management. More recently, concern has shifted to identifying alternatives to regulation as a means for risk management. Two key issues can be posed about such alternatives:

- Which alternatives to regulation demonstrate the greatest potential for managing specific technological risks to health, safety and the environment?
- What principles should govern federal reliance on alternatives to regulation for purposes of risk management?

Current Situation

The central argument for government regulation is that free markets sometimes do not produce a desired level of health and safety because prices to consumers do not reflect true social values due to so-called externalities. An externality exists if the costs of production or consumption are not reflected in prices to consumers. Several types of externalities may create problems for a free market. One consists of accidents that injure people other than the person in control. Another concerns the financial support given an individual who becomes disabled or the dependents of an individual who is killed. A third externality is the loss faced by family, friends, employer, and community when someone is killed. The market may also produce an insufficient level of safety as a result of imperfections in the marketing of products.

Consumers tend to desire government action in situations where individual action is not possible or is very costly and where existing institutions do not appear to be lowering the risk or protecting them against the loss as inexpensively as they believe it can be done. Some of the support for increased regulation probably reflects a general belief that an increasingly wealthy society should trade off more private goods for improved health and safety. Finally, paternalism seems to be a force behind the call for regulation. A variety of existing laws are designed to prevent individuals from voluntarily endangering themselves, especially those who are not fully capable of weighing the consequences of their actions. Regulation is also used to protect those especially vulnerable and in situations where appraisal and control of risks requires a technical expertise few people possess.

Even though good reasons may exist for government intervention, the question of whether or not to regulate is ultimately an ethical issue. Regulation generally results in an involuntary incremental cost being imposed on some citizens. If this cost is small compared to perceived benefits of making people safer, then most people would probably be in favor of government action, but even so reasonable individuals might disagree.

A number of more practical arguments can also be made. First, the thousands of hazards, dispersed throughout the nation, pose a virtually impossible management problem for the federal regulatory approach. Second, risk analysis is a difficult process with uncertain results, especially where there is a lack of data on fundamental issues. Establishing the findings of fact necessary to support regulatory action on a nationwide and generic basis is a complex task, particulary when the action seeks to manage risks in the distant future. Third, efforts to manage risks by federal regulation are costly, with the economic burden falling eventually on the taxpayer and consumer. Finally, federal regulation offers little incentive—or even justification—to states, local governments or the private sector to develop cost-effective programs to meet their own risk management needs. There is now sufficient evidence to indicate that health, safety and environmental hazards are too large, too variable and too costly for the federal regulatory approach alone. Nevertheless, the public still expects these hazards to be properly managed and risks to health, safety and the environment to be reduced. Critics of regulation have sponsored a wide variety of reform proposals.

The most obvious of the available alternatives is *industrial self-regulation*. Private firms invest considerable resources each year in developing and revising internal health and safety standards to govern their own activities. Many federal agencies have traditionally relied extensively, in their rule-making processes, on standards developed in the private sector. Since such regulations require of industry no more than what is required of itself, it is logical to suggest that private standards need not be promulgated as regulations, but can affect industrial risk management without any regulatory action.

The threat of liability may sometimes be a significant enough factor to stimulate a firm to adopt voluntary risk

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management standards. Private actions at *common law* can be regarded as a second alternative to regulation. Common law can motivate those whose conduct involves risk to adjust their activities in order to avoid potentially ruinous liabililty. This effect will occur even though the common law may not provide a specific standard of conduct—such as might appropriately be promulgated in a regulatory proceeding—by which to evaluate the conduct. Indeed, unsafe products have been driven from the market (or "voluntarily" withdrawn) because of the fear of liabaility even before regulators could act.

Insurance, a third alternative to regulation, is perhaps the oldest institution that formally addresses the problem of risk. As insurers strive to adjust the rates they charge for coverage to reflect more precisely the risks being insured, the focus of their concern is increasingly on risk management goals. Their efforts can be expected to continue to increase as federal agencies replace substantive regulation with "financial responsibility" requirements—compelling the purchase of liability insurance by those engaged in activities involving risk.

A fourth alternative to regulation is the provision of *consumer information*. Some imperfections in the market may reflect an imbalance between sellers and consumers in the level of information on such matters as health, safety or environmental risks. Consumer behavior will reflect environmental consequences or health and safety risks only if information about such factors is available to consumers. One way to achieve a more optimal level of risk management, then, is to assure that such information is provided.

Contract negotiation is a fifth alternative to regulation. In theory, if not always in practice, every health, safety or environmental risk that can be defined can be the subject of negotiated agreement between those whose activities create the risk and those upon whom the risk will fall. If the risks are understood and all the parties affected participate in the negotiations, the result should be a risk management plan satisfactory to all.

Since the Federal Government is both the largest employer and largest consumer in the United States, *federal influence* on risk management decisions made in the economy can also be a substantial alternative to regulations. Federal procurement restrictions, for example, have often been used to pursue social goals beyond the immediate objectives of the particular procurement. Merely by focusing federal attention on a particular issue, the government can create the necessary impetus for others to resolve it.

The following principles or criteria should be considered to assure selection of appropriate risk management options:

(1) *Risk Reduction*. What is the level of residual risk after the option is implemented? How does the level of residual risk compare with that of other options?

(2) *Economic Efficiency*. Will the option under consideration be cost-effective vis-a-vis other methods of risk management? What level of economic resources does the option require compared to others? Does it achieve the greatest risk reduction for the resources required?

(3) *Equity*. Will the option under evaluation be fair in terms of the allocation of costs and benefits over time, and afford due process to all affected, legally-recognized interests? Will people perceive the option to be fair? For example, will children, the helpless, and those most at risk be protected? Are the costs of risk reduction being paid for by the right group?

(4) *Transparency*. Will the public understand how the option works? Will they generally have faith that such an option will produce the desired outcome?

(5) *Evidentiary Considerations*. Will the option function without imposing unrealistic evidentiary burdens on the parties with interests at stake? Will it be workable on the basis of findings of fact that are technically and economically achievable?

(6) *Consistency and Uniformity*. Will similar risks be dealt with a similar fashion? Will the option be relatively uniform in operation in all jurisdictions, so as to prevent risk generators from "shopping around" and subsequent inequitable outcomes?

(7) *Accessibility to the Parties*. Will the option enable the parties to have access to the risk management arena in which the option is to be applied? In other words, will the option provide for procedural due process?

(8) *Administrative Simplicity*. Will the option be simple to implement? Will implementation require relatively few resources?

(9) *Self-reinforcing Considerations*. Will the reaction to the first attempts at implementation tend to bring forth better data, more information generally, and more positive reactions, so that subsequent modifications will improve the effectiveness of the plan?

(10) *Efficacy Overall:* Will the options under evaluation achieve socially desired "pre-loss" levels of risk reduction and risk prevention, and provide socially-desired "post-loss" remedial measures?

Research Agenda

Based on the foregoing, three critical research questions and issues can be identified. Proposals should address:

(1) To what extent do the various proposed alternatives to regulation differ across these ten evaluative criteria?

(2) To what extent do the various proposed alternatives to regulation differ along these criteria *for different types of risk problems or risk contexts* (e.g., consumer, occupational, and environmental contexts)?

(3) How will the various proposed alternatives to regulation interact with one another in theory and implementation? To what extent is it possible to integrate regulatory and non-regulatory strategies?

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Solicitation Topic No. 6

RISK AND UNCERTAINTY

Prepared by:
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Problem

Many technological hazards are characterized by substantial uncertainty. Recent examples which have attracted public attention include nuclear waste disposal, acid rain, carcinogens in food, and hazardous waste contamination. Dealing with uncertainty in such areas is a difficult problem for risk analysis and public policy making.

Current Situation

The first generation of formal risk analysis methods attempted to support policy and decisionmaking through quantitative assessment. Experience with these methods revealed significant problems related to the presence of irreducible uncertainties. The need for a second generation of risk analysis methods which will refine and extend our ability to deal explicitly with uncertainty has now become apparent. No single method or set of methods can be expected to be adequate to the task, however because different sources of uncertainty give rise to different classes of problems. At least four primary classes of uncertainty can be identified.[1]

Uncertainty about facts renders the future consequences of present decisions uncertain. Examples include uncertainties about present and future states of the world, the range of feasible alternative actions, and the processes that determine transitions from present to future states. Uncertainty about *values* makes decisionmakers unsure about what actions to take, even if there is no uncertainty about facts. The fundamental problem in this regard is how to evaluate the desirability of alternative actions and outcomes. The problem of aggregating individual preferences when collective decisions must be made is especially difficult. Uncertainties about appropriate ***risk attitudes*** often lead to debates over the level of acceptable risk in specific situations because of different attitudes about the desirability of accepting risks or taking gambles. Uncertainties about appropriate ***risk definitions*** make it difficult to formulate coherent questions about risks or understand the answers to the questions. Risk analysis is full of uncertainties about the meaning and the interpretation of key concepts such as ***risk*** and ***probability***; such uncertainties obscure the basis for risk management.

The four types of uncertainty give rise to a broad and pervasive range of difficulties within the risk analysis process. Difficult tradeoffs are required between investing limited resources in the control and management of known risks versus identifying new risks or reducing the uncertainty about ill-understood ones. Risk analyses must routinely be carried out in the face of incomplete and inadequate data. Insufficient data make it difficult to detect and validate suspected public health risks. Lack of certainty about the nature of relevant causal systems makes it difficult to describe or define the risks. Techniques available for estimating risk rates from partial data or sparse data sets are inadequate, and there are no accepted approaches for systematically incorporating uncertainty into evaluations of the severity of risks. Moreover, there are no accepted techniques for selecting an optimal set of variables to monitor the performance of risk management programs.

Uncertainty not only manifests itself in problems within the risk analysis process per se, but also leads to difficulties within the broader social, organizaitional, and institutional context of risk analysis. Perhaps the most difficult problem is how to take into account individual differences in values and risk attitudes when making aggregate social decisions about the management of uncertain risks. Somewhat less difficult in theory, but seemingly no less so in practice, are the problems associated with resolving people's differences about "facts" in collective decisionmaking under uncertainty. A general problem in this regard is how best to use expert judgments when critical data is uncertain or missing. An ancillary issue is how to deal with the uncertainty that the experts themselves may express about their estimates. More generally, little is known about the best institutional and organizational arrangements for collecting and disseminating information for the analysis and management of uncertain risks.

Research Agenda

A critical need exists for the development of a second generation of risk analysis mehtods that will improve and advance our abilities to deal with uncertainty. Research proposals in response to this solicitaiton should show clear promise of leading to better methods for collecting, analyzing, or making use of information for social decisionmaking about risks under conditions of uncertainty. Specific topics and questions of central importance are enumerated below. Research proposals should offer to develop theories or information to address most if not all of these issues.

Estimation of Low-Probabilty Events. Is it meaningful

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to try to estimate or communicate low probabilities? Are existing fault-tree and event-tree methodologies adequate?[2] How can nonstatistical inferences, based on engineering models and judgments, rather than actual observations, be made rigourous and/or reliable.[3]

Dealing with Model Uncertainty. Possible topics of investigation include determining appropriate levels of detail and disaggregation in modeling;[4] identifying model components that need further refinement; and evaluating model robustness and sensitivity.

Representations of Uncertainty. How can a meaningful, standardized index be constructed to represent the results of risk analyses in an understandable way?[5] Is numerical probability the best way to represent uncertainty? Should uncertainties be assigned numerical values at all? Would classification by *type* better capture the multidimensional nature of uncertainties?

Description of Risks and Benefits. For purposes of communication, what are the most effective terms in which to describe uncertainties in risks and benefits?[6]

Data Collection Strategies. Is collecting information after an accident a good rule? What "starting rules "should one follow? What "stopping rules" should one follow?[7]

Role of Incentives in Risk Analysis and Management. What are suitable institutional mechanisms (e.g., risk sharing pools, insurance) for management of uncertainty? Are incentives useful or necessary for eliciting high-quality information from experts? What incentives might induce individuals to pool private information to allow more effective management of risks?[8]

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Solicitation Topic No. 7

SAFETY CONCEPT PAPER

Prepared by:
Policy Sciences Section
Division of Policy Research and Analysis

Problem

The level of safety of complex enterprises is highly dependent on the level and form of regulation. There are situations in which more safety regulations do not necessarily lead to greater safety of operation, especially if the regulatory approach involves the imposition of increasingly detailed requirements, burdensome reporting, and high levels of specificity. In such situations, acutal safety performance may be degraded because the system resulting from the regulations becomes too complex.

Current Situation

The following definitions are provided to clarify the ensuing discussions.

- *System complexity:* A system is complex if it consists of interacting subsystems.
- *Measure of Complexity:* A measure of complexity is given by the number of simple components into which the subsystem can be decomposed. The intrinsic complexity of a simple component is not reducible.
- *Span of Comprehension and Control:* The span of comprehension is determined by the number of interacting subsystems that an operator or inspector can comprehend at any given time. The span of control is less than or equal to the span of comprehension.
- *Malignant Sequence of Events:* A sequence of events is called malignant if a sequence once initiated cannot be changed no matter what the mode of intervention.
- *Self-limiting Sequence of Events:* A sequence of events is self-limiting if without external intervention the system will settle in a safe state after a deviation from design condition has occurred.

Ultimately, as the level of regulation increases and the level of specificity reaches to the minutae, the regulatory burden can become counter-productive—that is, the level of safety achieved may be *lower* as the regulatory intensity increases. Indeed, designs may become so complex that interactions among the elements of the technical system become overwhelmingly critical, and unanalyzable. The responsibility for safety may be shifted toward the regulator; all that an operator must do is meet the applicable regulations.

The safety and reliabilty of a highly complex system may be specified in terms of the desired systems performance, e.g., a nuclear plant with some specified level of energy output and an associated probability of core melt not to exceed one event for 10^4 reactor years. Such a highly aggregated specification is beyond the span of comprehension as well as control of the operator or inspector. Thus, the system must be described in a less aggregated manner. Disaggregation could be taken to the extreme where the specification is given at the level of simple components. Here, the operator's ability to comprehend the interactions of the simple components is the limiting factor. Beyond a certain critical level of specification, there are more possible events leading to malignant sequences than the operator is able to diagnose or respond to.

There are two extreme cases in safety specification. In the first, the entire system is treated like a "black box", i.e., only inputs and outputs are specified. In case of any deviation from design conditions the operator has no way to analyze the system performance. Safety is built-in; if an event occurs that might lead to a malignant sequence, the operator is lacking the appropriate information to act. In the other extreme case, information on system performance is so highly differentiated that the operator lacks the capacity to integrate the information in time to assure safety. The inability to analyze performance in one case and to integrate information in the other leads to equivalent conditions of "no safety." A plot of "safety" versus "complexity" passes through zero in the extreme cases mentioned. In the simplest instance, the function would be given by the level at which the curve reaches a maximum. The practical question is at what level of complexity this maximum is obtained.

The ability to correctly diagnose a criterion value (e.g., unsafe system conditions) on the basis of the values of a set of diagnostic cues (e.g., violations of system regulations or standards) is a function of five factors: (1) *formal characteristics* of the system; (2) the *validity* of the diagnostic cues; (3) the *precision* with which such cues can be measured; (4) *intercorrelations* among cues; and (5) the *number* of cues.

Formal characteristics of the system refer to patterns of interconnection among system components. At one extreme are systems which can be defined by discrete states an deterministic relations among system components. At the other extreme are systems which must be defined in terms of continuous states and probabilistic relations among system components. Appropriate diagnostic strategies are different for these two types of systems. In the first type, the failure of a single simple system component may lead in a deterministic manner to unsafe conditions. Failure of a component implies potential failure for the system. Diagnostic strategies rely upon the monitoring of critical simple system components(s).

In the second type of system, states of system components and subsystems can be measured only along a continuum, usually with some error. The relations between measured values and system safety are probabilistic. Thus, a diagnostic model for system safety which integrates multiple pieces of information must be developed. For such systems, four additional factors come into play.

The validity of a diagnostic cue is defined as the correlation between its values and the criterion state, correcting for any random error in the cue or criterion. The validity of diagnostic cues for system safety is related to the level of specificity at which the system is described. If validity is plotted as a function of the level of detail at which a system is specified it will approximate an inverted U-shaped form. The correlations between system safety and the condition of simple system components or global system performance will generally be low. Maximum levels of diagnosticity will be obtained from information about the performance of the system at some intermediate level (e.g., at the subsystem level).

The precision, or reliability, of cues refers to the lack of "noise" in their measurements. Greatest precision can ordinarily be obtained from measures at the most elemental levels of a system. High levels of precision are also often obtained at highly aggregated levels of system specification, particularly when such measurements represent aggregations of "noisy" information from lower levels (since the random error associated with measurements is "averaged out.") The lowest levels of precision are normally found for measures at intermediate levels of system specificity. Subsystem performance, for example, can rarely be measured with the same precision as the performance of individual components. Precision and validity are thus frequently in opposition. The most valid predictors of unsafe conditions may be the most difficult to measure with precision.

If diagnostic cues are highly redundant (i.e., highly intercorrelated), diagnostic ability as a function of number of cues quickly approaches an asymptotic level. In general, the number of cues required to approach optimal diagnostic accuracy is smaller when measures are highly redundant than when intercorrelations are low. Paradoxically, predictive accuracy may be improved more by adding a less valid cue than by adding a more valid cue, if the correlation of the less valid cue with cues already in the diagnostic model is lower than the correlation of the more valid cue with ones already in the model. There is a tendency to continue to incorporate more and more cues into diagnostic models. Such increases ordinarily produce a rapidly diminishing marginal rate of return in terms of diagnostic accuracy. Accuracy may even be diminished in absolute terms, if increasing the number of cues decreases the precision with which each is measured, as is frequently the case in practice, if not in theory.

The optimal number of cues for diagnosing safety cannot be appropriately estimated in the absence of information about the validity, precision, and intercorrelations of such cues, but the optimal number of cues for diagnosing safety is usually less than the maximum number. In addtion, human cognitive limitations are such that, under a wide range of conditions, people become increasingly inconsistent in their judgment as a positive function of the numbers of cues to which they must attend. Providing people with more information, which may theoretically improve their diagnostic ability may, in practice, have the opposite effect because the additional cues result in greater inconsistency in diagnostic judgments.

A well-developed theoretical foundation exists for constructing diagnostic models. The theory takes into account the various interrelated factors that most affect diagnostic performance; the most important factors are cue validity, precision, interrcorrelation, and number. The implications of the theory are sometimes counterintuitive. For example, the ability to diagnose unsafe conditions will not always improve as a function of adding more diagnostic cues, even valid ones. For those situations where responsibility for making diagnoses of unsafe conditions rests with a human operator, there exists a complementary theory of human information processing capabilities and limitations. The theories can be profitably applied to problems of diagnosing and regulating system safety.

Research Agenda

Important research questions exist about the interrelationships among system safety, level of regulation, degree of specificity of regulation, man-manchine interactions, and human cognitive capabilities and limitations. Research proposals should offer to develop theories and information to answer the following types of questions:

1. Can systems elements and subsystems become so numerous and so complexly interrelated that operators understand so little about the systems they nominally control that safety is reduced?
2. Do situtations currently exist in which the time, effort, and resources required for complying with regulations is so great that system safety is adversely affected?
3. What are the advantages and disadvantages of computer-supported systems for aiding operators in diagnosing unsafe operating conditions?
4. Are safety regulations sometimes specified in such a way that they tend to reinforce behaviors that are not those which would be optimal for assuring safe operating conditions?
5. What links can be developed between systems theory and cognitive psychology that have practical implica-

tions for establishing optimal levels of regulation?

6. What factors need to be included in a general theoretical framework for specifying the relationships between system safety and level and degree of regulation? How important are formal characteristics of the system? Information-theoretic considerations? Human information processing capabilities and limitations? Human factors contributing to unsafe conditions.
7. Can test construction theory (and related statistical notions) be profitably applied to the problem of establishing regulations and designing detection systems that ensure timely detection of unsafe system conditions?
8. What is the best manner to assign responsibility for assuring system safety? Can regulations have detrimental or facilitative effects in this regard?

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1. Wohl, Joseph G., Cognitive Capability vs System Complexity in Electronic Maintenance, *Proceedings of Workshop on Cognitive Modeling of Nuclear Plant Control Room Operators*, August 15-18, 1982, NUREG/CR-3114, 170-173.
2. Okrent, D., Apostolakis, G. and Whitley, R., On PRA Quality and Use, UCLA School of Engineering and Applied Science, October, 1982, UCLA-ENG-8269.
3. Tochiyuki, Inagaki, Optimizaion Problems On System Supervision, in G. Apostolakis, et. al. Eds., *Synthesis and Analysis Methods for Safety and Reliability Studies*, NATO Advanced Study Institute Series, Plenum Press, 1979.

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DIVISION OF
POLICY RESEARCH AND ANALYSIS
EVALUATION SHEET

INSTITUTION	PRINCIPAL INVESTIGATOR	PROPOSAL NO.
PROPOSAL TITLE		

PLEASE RETURN TO: ____________________ NATIONAL SCIENCE FOUNDATION
WASHINGTON, D.C. 20550
BY ________________ (DATE)

	(Check where applicable)					Reasons for your rating are an important input to our evaluation. Please describe and discuss.
	Exc	V.G	Good	Fair	Poor	
1. Relevance of Proposed Research to Program						
2. Research Approach:						
a) Research Design & Methods						
b) Adequacy of Data						
c) Data Analysis Plan						
d) Objectivity and Balance of Approach						
3. Project Management Plan						
4. Professional Staff						
a) General Competence						
b) Relevant Experience						
5. Overall						

Please provide additional comments, either to amplify remarks above, or on any other criterion relevant to your evaluation of this proposal: e.g., capabilities of the institution, such as library facilities or special user ties; ability of the project staff to carry out the project in an objective and balanced manner (including consideration of other sources of support); cost effectiveness of the study. (Use extra sheets as necessary.)

Verbatim but anonymous copies of reviews, ratings and associated correspondence will be sent only to the principal investigator/project director on request. Subject to this NSF policy and applicable laws, including the Freedom of Information Act, 5 USC 552, reviewers' comments will be given maximum protection from disclosure.

REVIEWER'S NAME (TYPED OR PRINTED)	REVIEWER'S SIGNATURE	DATE

NSF FORM 1053 (4-82)

ADDENDUM REVISION (8/5/83) TO COVER PAGE - NSF 83-57

PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

Cover Page

FOR CONSIDERATION BY NSF ORGANIZATIONAL UNIT (Indicate the most specific unit known, i.e. program, division, etc.)	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? Yes ____ No ____ ; IF YES, LIST ACRONYM(S):
PROGRAM ANNOUNCEMENT/SOLICITATION NO.:	CLOSING DATE (IF ANY):

NAME OF SUBMITTING ORGANIZATION TO WHICH AWARD SHOULD BE MADE (INCLUDE BRANCH/CAMPUS/OTHER COMPONENTS)

ADDRESS OF ORGANIZATION (INCLUDE ZIP CODE)

TITLE OF PROPOSED PROJECT

REQUESTED AMOUNT	PROPOSED DURATION	DESIRED STARTING DATE
PI/PD DEPARTMENT	PI/PD ORGANIZATION	PI/PD PHONE NO.

PI/PD NAME	SOCIAL SECURITY NO.*	SIGNATURE	MALE*	FEMALE*
ADDITIONAL PI/PD				
ADDITIONAL PI/PD				
ADDITIONAL PI/PD				
ADDITIONAL PI/PD				

FOR RENEWAL OR CONTINUING AWARD REQUEST, LIST PREVIOUS AWARD NO.:	SUBMITTING ORGANIZATION IS: ☐ For-Profit Organization; ☐ Small Business; ☐ Minority Business; ☐ Women-Owned Business; (See cover page instructions, Page 3)

*Submission of social security numbers is voluntary and will not affect the organization's eligibility for an award. However, they are an integral part of the NSF information system and assist in processing the proposal. SSN solicited under NSF Act of 1950, as amended.

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW:

- ☐ Animal Welfare
- ☐ Endangered Species
- ☐ Historical Sites
- ☐ Human Subjects
- ☐ Marine Mammal Protection
- ☐ Pollution Control
- ☐ National Environmental Policy Act
- ☐ Research Involving Recombinant DNA Molecules
- ☐ Proprietary and Privileged Information

PRINCIPAL INVESTIGATOR/ PROJECT DIRECTOR		AUTHORIZED ORGANIZATIONAL REP.		OTHER ENDORSEMENT (optional)	
NAME		NAME		NAME	
SIGNATURE		SIGNATURE		SIGNATURE	
TITLE		TITLE		TITLE	
DATE	TELEPHONE NO. Area Code:	DATE	TELEPHONE NO. Area Code:	DATE	TELEPHONE NO. Area Code:

(SEE INSTRUCTIONS ON
REVERSE BEFORE
COMPLETING)

SUMMARY
PROPOSAL BUDGET

OMB No. 3145-0058
Exp. Date 12/31/85

	FOR NSF USE ONLY		
ORGANIZATION	PROPOSAL NO.	DURATION (MONTHS)	
		Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)	NSF FUNDED PERSON-MOS.			FUNDS REQUESTED BY PROPOSER	FUNDS GRANTED BY NSF (IF DIFFERENT)
	CAL.	ACAD	SUMR		
1.				$	$
2.					
3.					
4.					
5. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)					
6. ( ) TOTAL SENIOR PERSONNEL (1-5)					
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POST DOCTORAL ASSOCIATES					
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					
3. ( ) GRADUATE STUDENTS					
4. ( ) UNDERGRADUATE STUDENTS					
5. ( ) SECRETARIAL-CLERICAL					
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A+B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)					
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $1,000:)					
TOTAL PERMANENT EQUIPMENT					
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)					
2. FOREIGN					
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ ____________ 2. TRAVEL ____________ 3. SUBSISTENCE ____________ 4. OTHER ____________					
TOTAL PARTICIPANT COSTS					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES					
2. PUBLICATION COSTS/PAGE CHARGES					
3. CONSULTANT SERVICES					
4. COMPUTER (ADPE) SERVICES					
5. SUBCONTRACTS					
6. OTHER					
TOTAL OTHER DIRECT COSTS					
H. TOTAL DIRECT COSTS (A THROUGH G)					
I. INDIRECT COSTS (SPECIFY)					
TOTAL INDIRECT COSTS					
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)					
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS GPM 252 AND 253)					
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$	$

PI/PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
		INDIRECT COST RATE VERIFICATION		
INST. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials - DGC Program

NSF Form 1030 (4-83) *Supersedes All Previous Editions*

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPM 233)

INSTRUCTIONS FOR USE OF SUMMARY PROPOSAL BUDGET (NSF FORM 1030) (10-80)

1. General

a. Each grant proposal, including requests for supplemental or incremental funding, must contain a Summary Proposal Budget in this format unless a pertinent program guideline specifically provides otherwise.

b. Copies of NSF Form 1030 and instructions should be reproduced locally as NSF will not supply the form.

c. A separate form should be completed for each year of support requested. An additional form showing the cumulative budget for the full term requested should be completed for proposals requesting more than one year's support. Identify each year's request (e.g., "First year ________," or "Cumulative Budget," etc.) in the margin at the top right of the form.

d. Completion of this summary does not eliminate the need to fully document and justify the amounts requested in each category. Such documentation should be provided on additional page(s) immediately following the budget in the proposal and should be identified by line item. The documentation page(s) should be titled "Budget Explanation Page."

e. Revised budgets must be signed and dated by the authorized organizational representative and principal investigator and submitted in at least the original and two copies.

2. Budget Line Items

A full discussion of the budget and the allowability of selected items of cost is contained in *NSF Grants for Scientific Research* (NSF 78-41), *NSF Grant Policy Manual—GPM* (NSF 77-47), and other NSF program brochures and guidelines. Following is a brief outline of budget documentation requirements by line item. *(NOTE: All documentation or justification required on the line items below should be provided on the Budget Explanation Page.)*

A., B., and C. Salaries, Wages, and Fringe Benefits (GPM 511). On the Budget Explanation Page, list individually all senior personnel who were grouped under A5, the requested person-months to be funded, and rates of pay.

D. Permanent Equipment (GPM 512 and 204.2). While items exceeding $500 and 2 years' useful life are defined as permanent equipment, it is only necessary to list item and dollar amount for each item exceeding $1,000; items over $10,000 require certification. Fully justify.

E. Travel (GPM 514). Address the type and extent of travel (including consultant travel) and its relation to the project. Itemize by destination and cost and justify travel outside the United States and its possessions, Puerto Rico, and Canada. Include dates of foreign visits or meetings. Fare allowances are limited to round-trip, jet-economy rates.

F. Participant Support Costs (GPM 518). Normally participant support may only be requested under specific science education programs or for grants supporting conferences or symposia. Consult *Grants for Scientific Research* or specific program guidelines.

G. Other Direct Costs.

1. *Materials and Supplies* (GPM 513). Indicate types required and estimate costs.
2. *Publication Costs/Page Charges* (GPM 517). Estimate cost of preparing and publishing project results.
3. *Consultant Services* (GPM 516). Indicate name, daily compensation (limited to $193/day), and estimated days of service, and justify.
4. *Computer Services* (GPM 515). Include justification based on established computer service rates at the proposing institution. ~~Include computer equipment leasing~~ *Purchase of equipment is included under D.
5. *Subcontracts* (GPM 623). Must be approved in advance. Include a completed budget and justify details.
6. *Other.* Itemize and justify.

I. Indirect Costs (GPM 530). Specify current rate(s) and base(s). Use current rate(s) negotiated with the cognizant Federal negotiating agency. See *GPM* for special policy regarding grants to individuals, travel grants, equipment grants, doctoral dissertation grants, and grants involving participant support costs.

K. Residual Funds (GPM 253). For incremental funding requests on continuing grants, enter the amount estimated to be in *excess* of 10% at the planned amendment effective date. If less than 10%, indicate: "none." Residual funds should *not* be reflected in budget categories A-I. A justification for carryover of funds in excess of 10% is required. For standard grants (GPM 252), the total estimated residual amount should be shown.

L. Item L will be the same as Item J unless the Foundation disapproves the carryover of funds. If disapproved, Item L will equal J minus K.

*Include computer leasing costs in ITEM G. 6, other.